The State of GIS Application in Flood Management of Bangladesh

A Dissertation for the Degree of Master in Disaster Management

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Abstract

Bangladesh is considered to be a country miserably affected by recurring floods with devastating dimensions exposing the national economy in the hands of nature. Complete flood control in the geographical context, particularly in the deltaic form is not at all a feasible option. Structural method of flood protection are neither economically viable nor these are environment friendly. Therefore, non-structural methods are becoming popular in mitigating flood disaster.

Among non-structural methods, modem flood forecasting and the association with real time data collection have increasingly found favour with countries prone to flood hazards. Flood risk mapping is required to provide information concerning flood risk areas and to establish flood protection and evacuation system. It has been identified that, timely flood forecasts and warnings are key elements to aid disaster preparedness, which in turn will reduce flood damages and human sufferings in a great extent.

The existing of collecting information on floods extent and there effects are not very reliable. The system depends heavily on field information, which sometimes is erroneous and at times cannot even be collected until the recession of the floodwaters (EGIS, Dhaka, June 1998). Information from GIS can b used to extract, which are difficult to access by traditional methods.

Use of GIS provide supplementary data in hydrology for such analysis and will lead to easier interpretation and understanding of flood phenomena and characteristics. The digital elevation Model (DEM) can be effectively used for simulation to get a complete model of the study area.

Flood Management encompasses many environmental, social and engineering constraints. Decision making, although complex and difficult, can be greatly helped by using mathematical flood models and Geographical Information System. FMM unites these technologies as a first step towards a spatial decision support tool for flood management. This research attempts to find out the extent of the use of GIS in the flood management of Bangladesh. Bangladesh Government has applied very sophisticated tools having GIS to monitor and mitigate flood hazard of this country. With the help of remote sensing technology GIS can manage flood in a very effective way. If the ongoing projects can be finished the losses can be minimised in many sectors.

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CHAPTER 1
INTRODUCTION

1.1 Background of the Study

For the management of natural or man made disasters sequential information on the changes of nature and environment is essential. Now a days remote sensing integrated with GIS has emerged as a most sophisticated information technology in the disaster management and hence helps in taking proper measures for pre and post disaster management.

Disasters are of a wide variety depending on the location of a country on the globe. Cyclones, floods, droughts, earth quakes, volcanic eruptions, forest fires, landslides, erosions etc are among the important natural disasters while there are human induced epidemics like environmental degradation, diseases, war etc. Remote sensing owes much to the satellite technology due to its synoptic, repetitive and multi-spectral nature in observing the surface of the earth be it in connection with the resources or the disasters occurring any where on it. With the advent of satellites cloud movement and formation of cyclones can be monitored, floods can be mapped, agricultural crops can be estimated alongside assessment of damages. The resource survey satellites carry onboard sensors that are capable of providing information on every natural feature that prevails on the surface of the earth.

The Geographical Information System (GIS) is a versatile tool added to the new technology which make the data acquired either through remote sensing satellites, aerial photographs or through physical surveys carried out for a purpose to be more useful to the decision makers and the planners. These technological provisions have made planning and development activities more handy towards achieving sustainable development.

Flood is the most devastating natural phenomenon that affects and disrupts the well being of the society, specially poor people who are vulnerable to disaster due to resource limitation. Most of the natural disasters in Asia are related to flood and causing maximum damage to lives and properties in comparison to other disasters. Bangladesh probably is the most affected country by natural catastrophes, especially the flood.

In 1993 within the framework of the Flood Action Plan (FAP) program, the Government of Bangladesh and the World Bank have assigned the USAID sponsored FAP 19 GIS (Geographic Information Systems) program component a supporting role to provide leadership in the development, application and institutionalization of GIS technology in Bangladesh. In order to organise, process and interpret spatial information for resource management and environmental monitoring, GIS relies on up-to-date remote sensing data as a source.

1.2 Objectives

The objectives are as follows

- To find out availability of GIS based flood map and vulnerability analysis of flood prone areas
- To find out the efficiency Flood forecasting and warning services provided by water modelling
- Recommend some points to improve the flood management system with GIS and modelling technology

1.3 Methodology

Primary and secondary data have been used for the purpose of research. Relevant books, **online** materials are being reviewed.

Secondary data were collected from **a number** of interviews with the officials of the organizations given below.

- Survey of **Bangladesh**
- Institute of Water Modelling
- Centre for Environmental and Geographic Information
- Flood Forecasting and Warning Centre
- Comprehensive Disaster Management Programme

CHAPTER 2

FLOODS IN BANGLADESH

Floods are natural and recurrent phenomena that inundate about one fifth of the country each year, while severe and devastating floods with a return period of 100 years inundate more than 60% of the country. The difference of peak water levels between 2 and 20 year return period is about 2 meter, with only I meter difference between 20 and 100-year return period. Due to the countries flat topography, just a small increase in water above the bank causes full-scale inundation. Flood affected areas of different return period floods are presented in table 1.

Table 2.1: Areas affected by floods of different return period

Return period	2	5	10	20	50	100	500
Area Affected (% of the Country)	20	30	37	43	52	60	70

Source: Environment and GIS Support Project for Water Sector Planning, 2000

2.1 Geographical factors responsible for flood

1) Surrounded by mountains

The country is surrounded by hills on its three sides. Rajmahal hills on the west, the Himalayas and the Meghalaya plateau on the north and tripura Chittagong hills on the east. The rainfall runoff from the vast hilly area coupled with snowmelt in the Himalayas bring a huge inflow of water to Bangladesh during the wet monsoon season. A large area including Bangladesh and the adjoining areas in India is under the influence of monsoons. From June to October large quantities of warm moist air travel from the Indian Ocean north over Bangladesh and then to the Himalayan slopes as monsoon winds.

2) Lower riparian country

Bangladesh is known as the land of rivers and the major rivers are the Ganges, the Brahmaputra and Meghna with a complex network of 230 rivers including 57 internationally transboundary rivers. the Ganges , The Brahmaputra and the Meghna are the large river systems in the world covering a combined total catchments area of about 1.6 million square km and extending over Bhutan, China, India, and Nepal of which only 7% falls in Bangaldesh.The total **annual** rainfall contributes to a flow of 250,398 million m3 whereas flow coming from outside the border amounts to 999,124 million m3 carried by the rivers of Bangladesh of which 90% comes during monsoon.

3) Flood plain country

About 80 percent of the country is floodplains composed of predominantly recent alluvial deposits transported from the hills by the rivers. Hill areas in the northern and eastern parts occupy about 12 percent and terrace **areas** in the centre and northwest occupy 8 percent. Because of the flat topography , flooding spreads evenly and accumulates on the **plains**. The alluvial rivers have natural levees at both banks, which slope down to back-swamps. There are numerous natural depressions, mainly in the northeast region where they are known as Haors, in the southern part of the northwest region where they are known as beels, and in the southwest and in the south central regions where they are known as Baors.

Topography of the country is mostly flat except in the northeast and southeast, which are hilly. The land elevation varies from 3 to 90 m MSL.More than 50% of the floodplain is within 5m MSL. The very location and the topography make the country vulnerable to floods.

2.2 Types of Flood

1) River flood

Main source of the flooding is the bank overflow from the major rivers . A broad strip of land adjacent to the rivers is subjected to this type of flooding. About 30 percent of the country is prone to river floods.

2) Rainfall flood

About 80 percent of the annual rainfall in Bangladesh occurs during June to September when the river flow at high stage due to huge inflow of waters from catchments outside the country. As a result drainage is impeded. Besides this, high intensity and long duration rainfall cause local flooding when the local river cannot drain quickly. Average annual rainfall for the whole country is about 2400 mm.

3) Flash Flood

In the northern and the eastern hill streams , flash flood occurs during the pre-monsoon months of April and May.

4) Tidal flood

The areas adjacent to estuaries and tidal rivers in the south west and south central parts get flooded twice a day due to astronomical tide from the Bay of Bengal. During spring tide which occurs fortnightly, large area is floods by tidal water. Tide is experienced up to 225 km inland in the wet season and 325 km in the dry season.

5) Storm surge flood

The storm surges due to tropical cyclones in the Bay of Bengal occasionally cause severe disaster in the coastal areas.

2.3 Historical floods

Flood is a regular phenomenon in Bangladesh. Almost every year floods affect the country seriously during the southwest monsoon (June to September). According to historical records (FFWC 2001) five devastating floods occurred **in the** 19th century (1842,1858, 1871, 1885,1892). And sixteen such floods occurred in the 20`h century. Hussain *et al,* (1987) report serious floods in 1954,1955, 1956, 1962, 1963, 1968, 1970, 1971, 1974, and 1984 (Brammer, 1999) The highest number of death was recorded **in 1988** flood, (2379 people). And the largest amount of damage caused by 1998 flood was estimated to be 270 million US$ as per the price of 2002. The estimated **annual** average flood damage is about 21 million US$.

The 1987 Flood

The severe flood in August-September 1987 was predominantly a rainwater flooding affecting the north western region of the country. However, flash floods also occurred in that year on eastern piedmont plains in late-June and August-September. In all, six separate floods were reported during the 1987 rainy season. Long term rainfall averages were exceeded by 300-700 **mm in** all four monsoon-season months in parts of the northwest. Many places had rainfall amounts of 100-150 mm on one or more days and 500-1000 mm or more in one or more 10 day periods.

The satellite image shows some points about 1987 flood.

1. Flooding of the Teesta and Karatoa-Bangali floodplains was by rainwater, except downstream from the breach in the Brahmaputra Right-bank embankment where the Jamuna broke into the Bangali river.
2. By contrast, on the eastern side of Jamuna River, which was not protected by an embankment, silty water spread a distance from the main river channel and Dhaleswari?

3. On the Ganges river floodplain, silty water was confined to the active **floodplain.**
4. Silty water was also confined to active floodplains of the Teesta, Dharla nad Dudhkumar rivers.
5. The silty water on the **Barind** tract disturbed the paddy fields

The 1988 ood

The 1988 floods were predominantly river floods. Heavy early monsoon rainfall in **the north-east of Bangladesh and over the adjoining Shilong Plateau brought the** Meghna and Brahmaputra rivers close to or above danger level foe a few days in **mid-July. The most serious floods occurred early in September following ten days** of exceptionally heavy rainfall at the end of August over north-east India, Nepal, **Bhutan and the northern part of Bangladesh.**

Several places in the north of the country recorded individual daily rainfall amounts **exceeding 100 mm and 10 day totals exceeding 500 mm (Sunamganj 1212 mm on** 20 August. Rainfall in August at several northern stations exceeded previous records, with return period frequencies of 50-100 years.

The satellite images indicate following points:

1. **Flooding was less extensive along the Teesta and Ganges rivers , except near** the Ganges Jamuna confluence where back up of water occurred.
2. There was extensive back up of water in the lower Atrai basin.
3. The **flooding in north-eastern region was less significant as it is used to be deeply flooded in the monsoon season.**

The 1998 Flood

The floods **in 1998 had many features common with the floods experienced in** 1988. The main difference were in the long duration of the flood in 1998 and a **greater contribution** of heavy **rainfall over Bangladesh.**

River levels rose rapidly in July. The rivers remained continuously at or above their respective danger levels for 26 days at Hardinge bridge on the Ganges, for 57 days at Bahadurabad on the Jamuna, and for 67 days at Bhairab Bazar on the Meghna.

Satellite images reveal some points:

1) **Brahmaputra right embankment was not breached.**
2) **The east bank embankment was also effective.**
3) Flooding was more extensive on the Ganges river floodplain tidal floodplain and Teesta floodplain.

2.4 Flood Management Of Bangladesh

Within the broad context of riverine flooding, The general objective of flood management would be to optimise benefit for the society, striking a balance between reducing the damage and exploiting the beneficial effects of floods. Flood management thus refers to al tasks related to the occurrence and impact of floods. Specific examples of flood managements are :

- Monitoring floods
- Proving Information
- Predicting floods and disseminating predicted values
- Designing and implementing flood protection infrastructure
- Operating regulators and reservoirs
- Allocating **land use in** floodplains
- Designing and implementing rehabilitation measures and
- Evacuating flood victims

Such flood management cannot be realised through one single management agency, but would required a well concerted integrated approach between all government and non-government organisations involved. It would also recognise and pay proper attention to at least the following **issues :**

The beneficial effects of flood: Floods have created the landmass of Bangladesh and to a large extent the agricultural conditions which **sustain** a population that is 80% of that of Russia, a country 100 times larger in area (James, 1993). An exclusive focus on excessive floods would disrupt the delta building process and, in the longer run, disbenefit society as well (Shahjahan, 1993; Rashid 1995).

The same flood can be beneficial or destructive for different floodplain users: Foe example, normal floods are generally considered beneficial for agriculture, but can be damaging for urban areas. Fisheries benefit from high floods, agriculture prefer normal flood conditions.

In addition to structural **measures**, flood management should consider non-structural measures such as flood proofing: flood insurance; income generation; evacuation and food security measures.

In the last few decades, flood management practices in Bangladesh were mainly concerned with finding ways to protect agricultural production. However, limitation of such a focus is visible now. Many areas in Bangladesh are now confronted with decline in quantity and quality of existing water resources causing adverse impact on the **natural** environment.

Flood management encompasses many environmental, social and engineering constraints. Decision making, although complex and difficult, can be greatly helped by using mathematical flood models and geographic information system.

In Bangladesh, the Ministries of Water Resources, Relief and Disaster Management, Agriculture, Fisheries and Livestock, and Establishment are the main ministries involved in flood management, and generation and dissemination of information. They encompass the following technical organisations to support policy and strategic decisions; Bangladesh meteorological Department(BMD), Bangladesh Water Development Board (BWDB), Flood Forecasting and Warning Centre (FFWC), Water Resources Planning Organisations 9WARPO), Bangladesh Inland Water Transport Authority (BIWTA),Local Government Engineering authority (LGED), CARE, Bangladesh Agriculture Research Council (BARC), Disaster Management Bureau (DMB), Space Research and Remote Sensing Organisation (SPARSO).

CHAPTER 3
FLOOD AND GIS

It has been identified that, timely flood forecasts and warnings are key elements to aid disaster preparedness, which in turn will reduce flood damages and human sufferings to a great extent. The existing system of collecting information on flood extent and their effects are not very reliable. The system heavily depends on field information, which sometimes is erroneous and at times cannot even be collected until the recession of the floodwaters. Information from GIS can be used to extract some types of information, which are otherwise difficult to access by traditional methods, particularly for flood forecasting and floodwater movement.

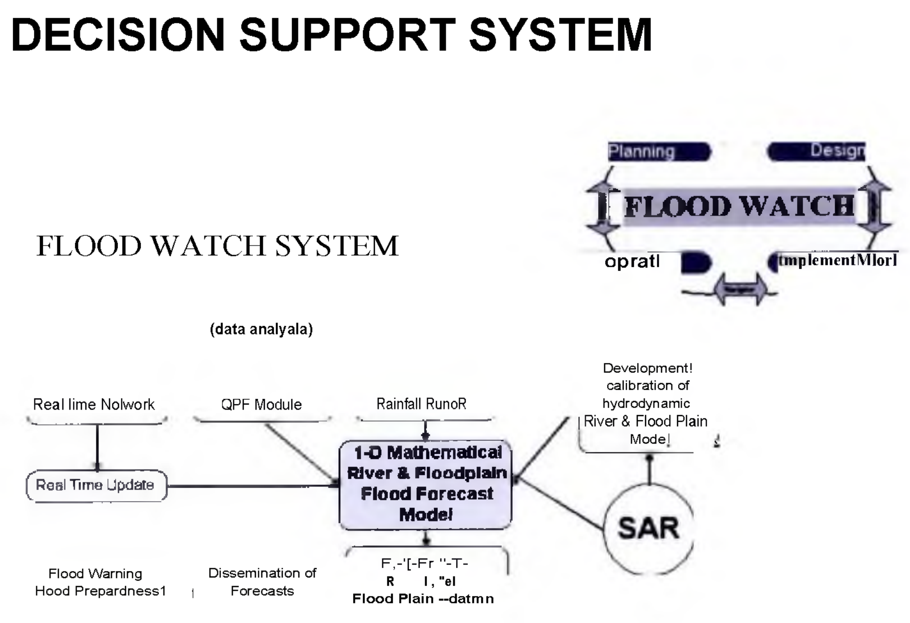


Figure 3.1: Flood Watch System
Source: Kjelds and Jorjenson , (n.d.)

3.1 MIKE 11 GIS **modelling system**

In 1995 a methodology was developed by integrating Danish Hydrodynamic Model MIKE 11 and GIS. The MIKE 11 flood forecasting system comprising of three modules of Rainfall Runoff model (NAM), Hydrodynamic model (HD) and Flood Forecasting (FF) model. Flood forecasting Warning Centre issues the forecast using the MIKE 11 and flood Watch Model systems. The services of FF&WC have been very effective in disseminating flood information and forecasts efficiently and accurately.

Each morning during the monsoon real time data (rainfall and water levels) are collected in the field from more than 70 stations and transmitted to the flood forecasting centre in Dhaka.

Model area	:	82,000 km2
Total river length :		7270 km
Catchments	:	216
River branches		195
Floodplain links	:	207
Structures	:	40
Boundaries	:	54
Grid Points		4200

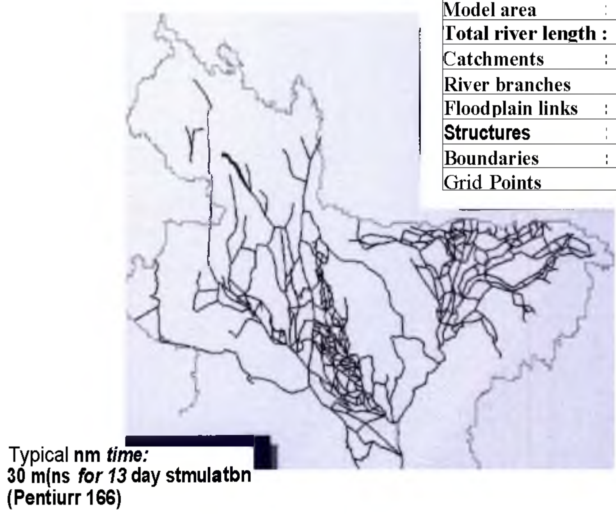


Figure 3.2: Northern Flood Forecast Model
Source: Kjelds and Jorgensen, (n. d.)

The MIKE 11 model developed and applied at the FF&WC comprises all major and secondary rivers in the northern part of Bangladesh, with a total catchment area on 82,000 km2. The schematised river system in the model has a total length of 7270 km describing a very complex flow pattern. Flood extents for selected areas are produced as flood inundation maps. This information is directly available in flood watch system for further analysis and comparison with remote sensing g data, such as satellite or SAR images. Application of SAR images, which can penetrate cloud cover, permitting accurate data acquisition foe calibration and validation seems very promising.

The MIKE 11 system includes extensive functionality for real time flood forecasting integrated in an ARC View GIS environment composed as a single user friendly interface. The system has proven its capabilities in the fields of planning and structure design, as well as real operation for flood forecasting.

The MIke 11 FF module includes the following components:

- Calculation of mean areal rainfall from point rainfall
- Calculation of discharge from water level data and rating curves or rating tables

- The NAM rainfall -runoff model, which calculates sub-catchment inflow to the river system
- The hydrodynamic model for routing the river flow and predicting water levels
- An automatic updating procedure which utilises the measured water levels to minimise differences between observations and simulations at the time of forecast
- Specification of quantitative precipitation forecasts and predictions of boundary inflows
- The MIKE 1 l GIS interface for mapping depth/area inundation

Merging the I dimensional MIKE 11 river modelling system with GIS technology integrates an accurate and advanced mathematical modelling tool with a spatial analysis tool. The derived holistic approach incorporates also advanced time series analysis tools and extreme value statistics with GIS. The integrated system makes it ideally suited as a core element in a "Decision Support System" which can be efficiently applied for all aspects of flood plain and river basin management.

In the planning and design phase, the MIKE II system is a valuable tool for determining civil works design criteria, designing flood control and drainage structure operation rules, and providing inputs to flood preparedness programmes..

At the implementation stage, MIKE 1 l may be useful for a range of needs from scheduling flood prone construction works to a flood preparedness training aid.

Flood models

Flood models are a necessary input for flood mapping, the main function and output of Flood Management model (The MIKE 1 I GIS Modelling system). To produce the flood maps, detail of a model's network and flood simulation results are required.

The flood Watch system is used to prepare bulletins, warning messages and graphical displays. Based on predicted flood extent a spatial flood map is prepared for TV showing areas affected including a flood warning status.

CHAPTER 4
LITERATURE REVIEW

An extensive review of literature and reports were conducted using the library facilities of CGIS, **Institute of Water Modelling (IWM), supplemented with documents and information gathered from the organisations and via the internet**

4.1 Mekong Hydrology Programme

The Mekong, like several other rivers in the developing worlds, is still undeveloped. It flows through six countries- China, Myanmar, Laos, Thailand, Combodia and Viet Nam.lt is the world's 12`h longest river, with length of 4800 km, a drainage area of 795000 km2. and annual runoff of 475000 **million** m3 inspite of its impressive **annual** average figure, the Mekong's discharge is subject to strong seasonal fluctuations. The ratio between peak and base flow is as high as 50:1

4.1.1 Mekong river commission flood forecasting activities

The forecasts are made of the water level from 1 to 5 days in advance for the stations in the upper and middle reaches by a synthetic model, SSARR (stream flow synthesis and river flow regulation) and from I day to 2 weeks in advance for those in downstream stations **in the** delta by a hydrodynamic flow model, Delta. SSARR has been introduced to the secretariat by US Corps of Engineers while delta has been through the UNESCO's support in the late 1960's and the earl 1970's. At present, only SSARR is operational at the secretariat for the routine forecast in every wet season

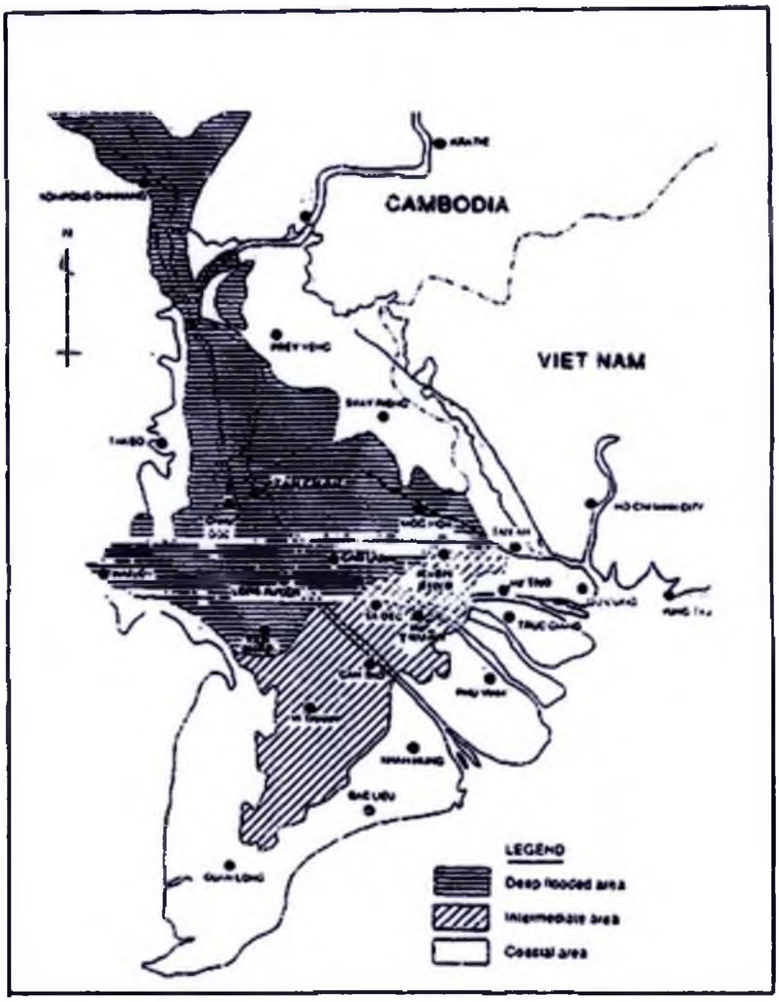


Figure 4.1: Flood Zone in the Mekong Delta (1996)
Source: Anonymous, (n.d)

Water level monitoring stations range from Chiang Saen in Thailand to Tan Chau and Chau Doc in Viet Nam's Mekong Delta. The result of the calculation is transmitted to the riparian countries through their respective National Mekong committees in a standardized reporting format within the same day.

The SSARR model has three components

1) The water shed model
2) The channel routing model
3) The reservoir model

In the water shed model the runoff is calculated by means of parameterisation of the conceptual runoff process which occur in the basin.

For channel routing a storage function is used in SSARR.

Flood forecasts in 1997

The peak water levels calculated by SSARR **for major stations stand within a reasonable range of errors at some stations, SSARR has marked almost the exact value of the observed water level.**

Table 4.1: Flood peak forecast by SSARR

CA	Q			Q
Chiang Saen	2 Oct 97	7.62	7.64	+ 0.02
Luang Prabang	7 Sep 97	16.56	n/a	n/a
Vientiane	9 Sep 97	11.34	11.21	-0.13
Paksane	10 Sep 97	14.74	14.78	+ 0.04
Nakhon Phanom	11 Sep 97	12.28	12.21	-0.07
Mukdahan	11 Sep 97	12.32	12.32	0

Source : Anonymous, (n.d.)

Although SSARR model is considered area out of date model, it is still useful for MRC and **the riparian** countries. The model environment should be improved with respect to the parameter calibration, the user interface, rainfall forecast system, hydrodynamic **simulation** of the delta **area**, incorporation of the Tonle Sap lake, and so forth.

The model uses ten day rainfall forecasts provided by the meteorology Unit of the Mekong River Commission Secretariat to produce estimates of discharges at specified locations.

4.1.2 Flood mapping offlood prone areas in Lao PDR

Rainfall and runoff in the Lao PDR provides 35% of the flow through the Mekong River Basin(MRB). In the last 20 years, the hydrology of this flow has been changing.

The flood management unit (FMU) views the flood management database from a spatial perspective. Using a spatial perspective **means** that quantitative and qualitative data, referred to as attribute data in a GIS, is collected and stored together with the associated geographic coordinates. This development of new information can be as simplistic as the calculation of population density by dividing population data by area or as complex as predictive modelling of a village's economic loss by analysing the interaction of.

- Flood depth
- Agricultural systems
- Population characteristics
- Public infrastructure and
- Economic conditions

As its GIS software FMU selected Arc View with the spatial analyst. With this the **user can** create a data surface with peaks and valleys known as Digital Terrain Model (DTM).

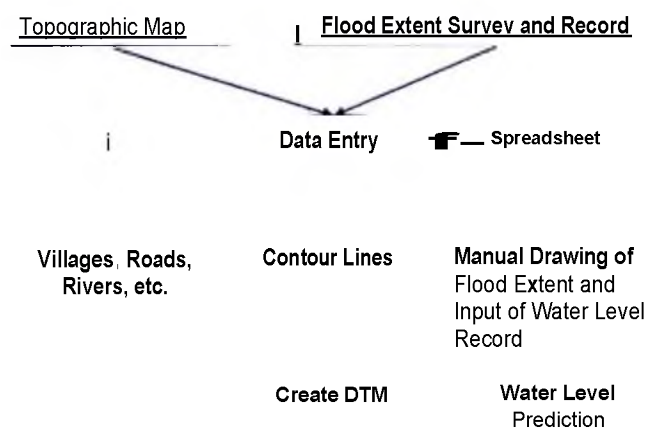


Figure 4.2: Data preparation flow chart
Source: Anonymous, (n. d.)

To check the performance of the GIS, the initial series of maps were produced. These are:

- 2-D basic infrastructure map
- 3-D basic infrastructure map
- Map of interpolated contours based on the DTM

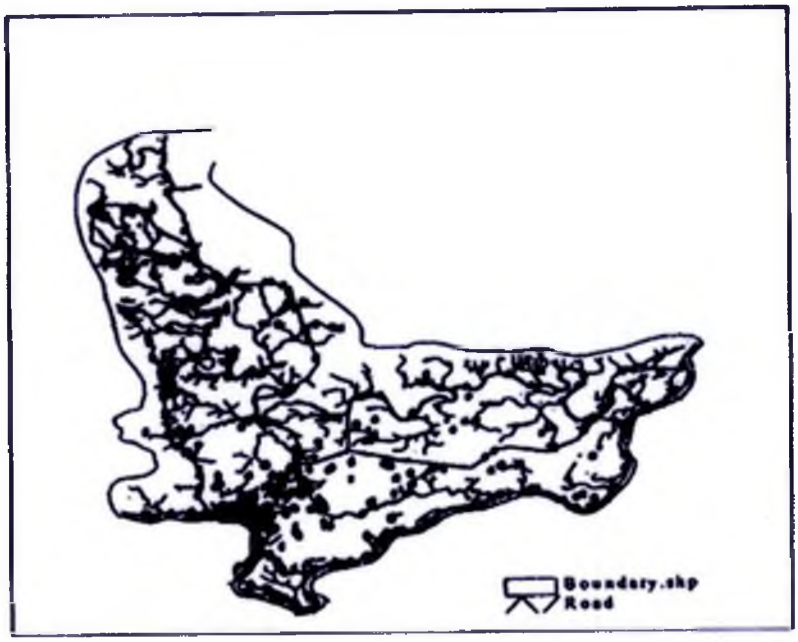


Figure 4.3: Basic Infrastructure map
Source: Anonymous, (n.d)

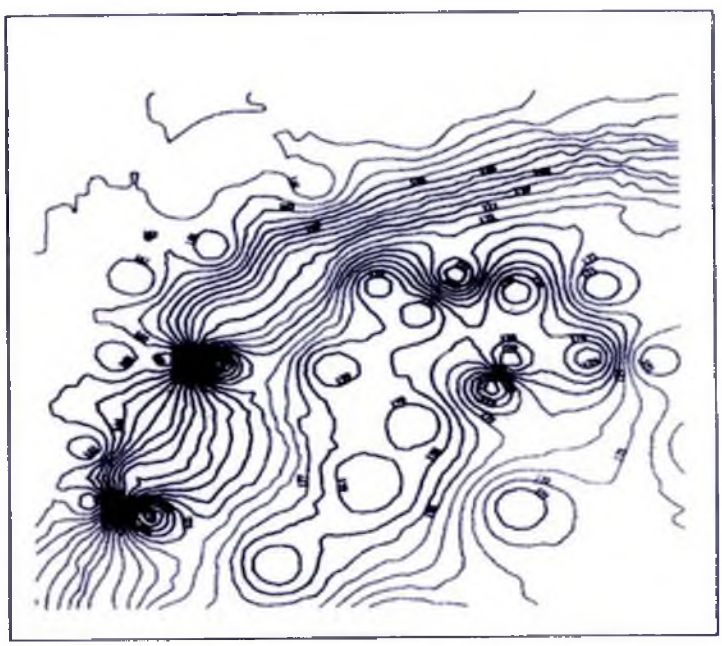


Figure 4.4: Contour line generated from DTM
Source: Anonymous, (n.d.)

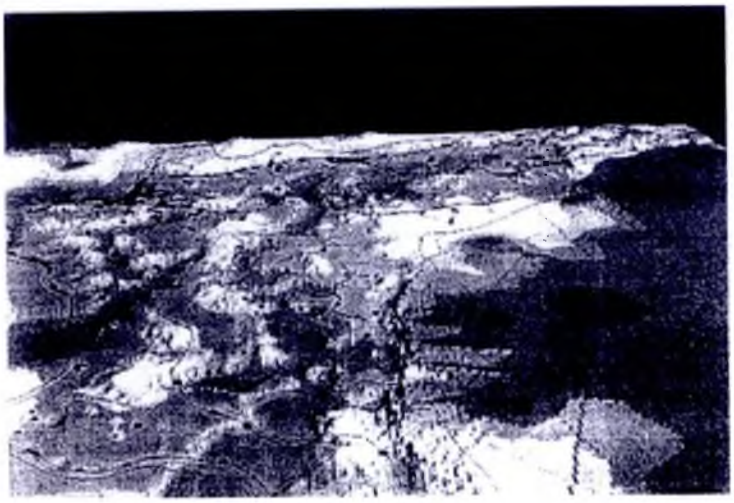


Figure 4.5: 3D Digital terrain model
Source: Anonymous, (n.d)

4.2 Flood forecasting system in China

The Songhua basin , located north eastern part of China, has a population of 62 million people. The flooding typically occurs at a time scale of the order of 20-30 days, depending on the characteristics of the weather. Typically two kinds of weather patterns occur.

High intensity precipitation with a short duration arriving from south, giving a relatively fast response. Persistent precipitation with a small intensity arriving from north and west of the basin, giving a slow flood response.

Owing to the fact that about 70-80 percent of the annual precipitation falls in the period June-September, most of the flood events occur in this period of the year. Areas at flood risk include the major city of Harbin, which is frequently affected by flooding from the main Songhua river.

In 1998, the extremely severe flooding of the Nen river and the Main Soghua river caused dike breaches at nearly a thousand different locations. The severe flood disaster hit the western regions of Heilongjiang and Mongolia autonomous region, causing several casualties, relocation of citizens and damages to property.

The Asian Development Bank (ADB) has granted a loan to The People's Republic of China to establish a long term solution that can provide early flood warning and help decision makers of the Songhua Water Resources Commission (SWRC) in their effort to mitigate and manage flooding. The project provide the following components which are integrated into a single system.

- ■Hydrological forecast models for the Songhua basin
- ■A real time GIS based flood management and forecasting system
- ■ A web based decision support system

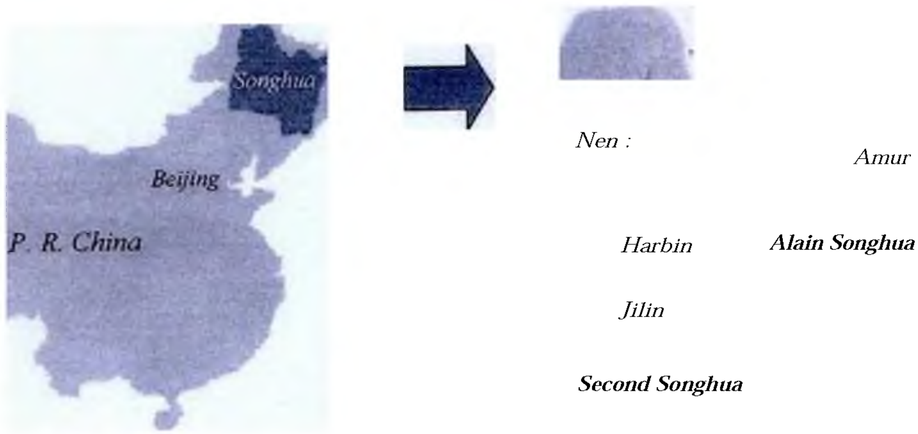


Figure 4.6: Songhua Basin,Telemetry Stations
Source: Skotner et al

The system comprises three different parts.

- A data part, the spatial data includes information on demography, infrastructure, damage curves and pre-cooked scenario simulations computed by use of MIKE FLOOD.
- A forecasting Shell that integrates real time data from MIKE FLOOD and several one and two dimensional forecasting models.
- A web server with a Java based web application.

The data is quality assured according to user defined quality criteria and stored in the On-Line system database. The system provides automated tools for the derivation of accurate and robust forecast model input time series to help improve the forecast accuracy and reliability. The system interfaces one dimensional models(MIKE 11), two dimensional models (MIKE 21) and a combination of the former two (MIKE FLOOD).System tasks such as import of real time data from remote data acquisition stations, initiation of forecast modelling tasks and dissemination of selected results to emergency staff, authorities and the public, are handled using a task scheduling facility, capable of running predefined tasks upon request by a user, as scheduled or in the case of an alarm.

The two **dimensional scenarios are not feasible to run in real time. Precooked scenarios are can be retrieved from one dimensional forecast models. Real time scenario simulations are based on one dimensional forecast models**

'figure 3 Example of pre-cooked ***scenario simulation*** *for the city of Jilin.* ***The simulation*** *portrays the floodplab aused by an* ***embankment failure.***

Figure 4.7: Precooked Scenario **Simulation**
Source: Skotner et al

Precooked scenario simulations have been made for four important flood protection cities and two flood detention areas. These can be used for emergency action plans or similar.

The real time scenarios are used to investigate one or more of the following issues:

a) Uncertainties in precipitation forecasts
b) Uncertainties in catchment runoff
c) Changed operations in major dams
d) Embankment failures at key locations

Filtering technology is used top improve hydraulic forecast. The state updating technology has been applied at 10 mainstream locations and 44 tributary locations spread across the basin. In the upstream part of the catchments, discharge updating has been applied, while in the downstream, highly inhabited areas, water level updating has been applied.

4.3 Case **Studies of Bangladesh**

4.3.1 Dynamic Flood Warning System In Sundarganj Thana

Sundarganj thana of Gaibandha district in Bangladesh is located in the in the northern part of the country bounded by two major rivers Brahmaputra in the eastern and Teesta in the northern part. Due to topographical condition the area is subjected to floods almost every year because of low gradient of the terrain. The terrain is alluvium flood plain and is not much stable as the river courses changes continuously. Flash flood is caused by the river Teesta and the river flooding by the river Jamuna.

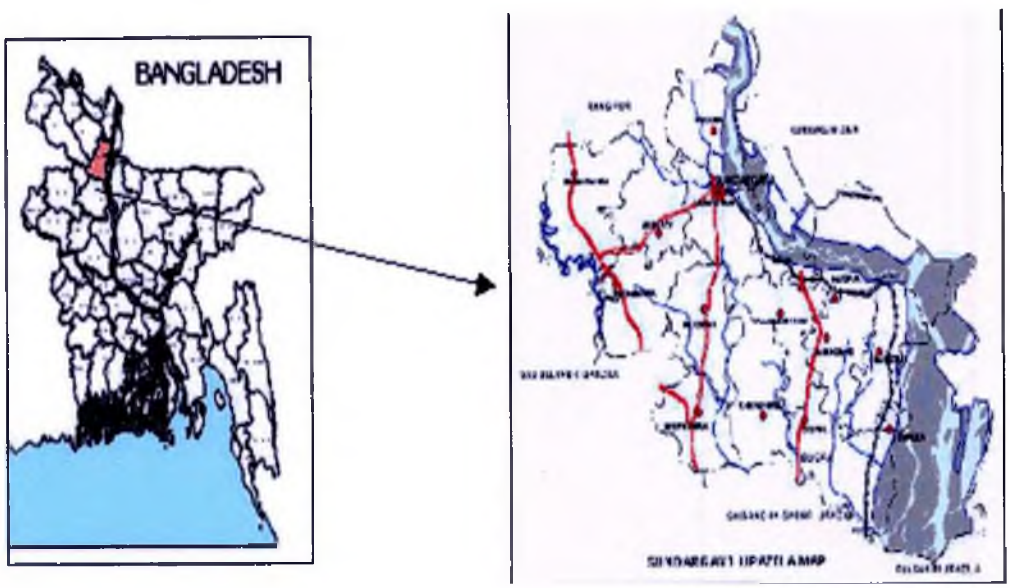


Figure 4.8: Sundarganj thana of Gaibandha District
Source: Aziz et al, (n. d)

The importance of the flood forecasting and warning is widely recognized as a vital non structural measures to aid the mitigating -the loss of life, crops and property caused by the annual flood occurrence.

Hydrodynamic model MIKE I I -FF (NAM, HD and FF) was successfully integrated with GIS in the Arc View GIS environment. GIS has been used intensively to create watershed models from digital elevation (DEM) data to trace flow paths to get a complete surface for identifying the actual flood Flow.

GIS was used for the analysis to determine hazard zones in the maps. This information leads to locate safer location to evacuate the affected population utilizing the optimum route. As the simulation results at every hour for the next 72 hours are available, so flood inundation maps can b prepared at any of those time stamps using the forecasting water levels.

Figure 4.9: Flood **phase maps of Sundarganj Thana**
Source: Aziz et al, (n.d.)

Water levels in the flood phase Maps. Dark blue showing higher water depth.

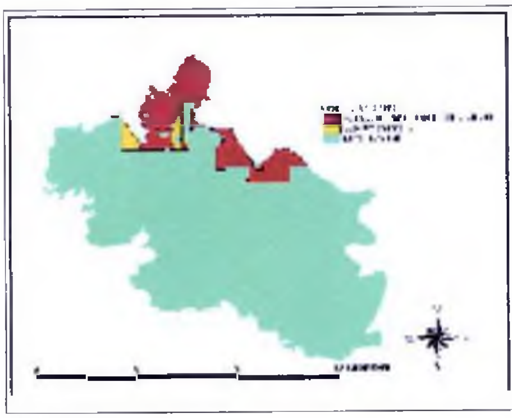


Figure 4.10 : Flood affected crops
Source: Aziz et al, (n.d)

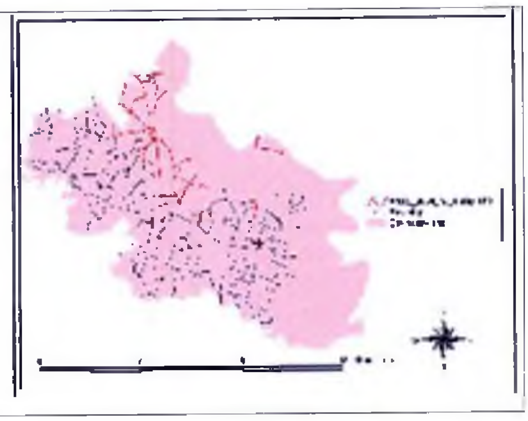


Figure 4.11: Flood affected Roads
Source: Aziz et al, (n. d.)

There is considerable crop damage almost every year of moderate flood. The area was then reclassified according to the types of crop. Sometimes the maps help to warn the local people to harvest crop early.

The following table shows the possible percentage of affected crops in the next 72 hours.

Table 4.2: Estimation of Affected Crops under 40cm Water Level in Sunderganj Thana

	Description	Affected Crop in Area (Sq. m)	Percentage (%) of Crop Affected
F	4-May	106311166.7	25.39
	5-May	49322655.14	11.78
	6-May	49009037.55	11.70

Source: Aziz *et al*,(n.d.)

There are also maps that indicate the accessible route to evacuate people during emergency.

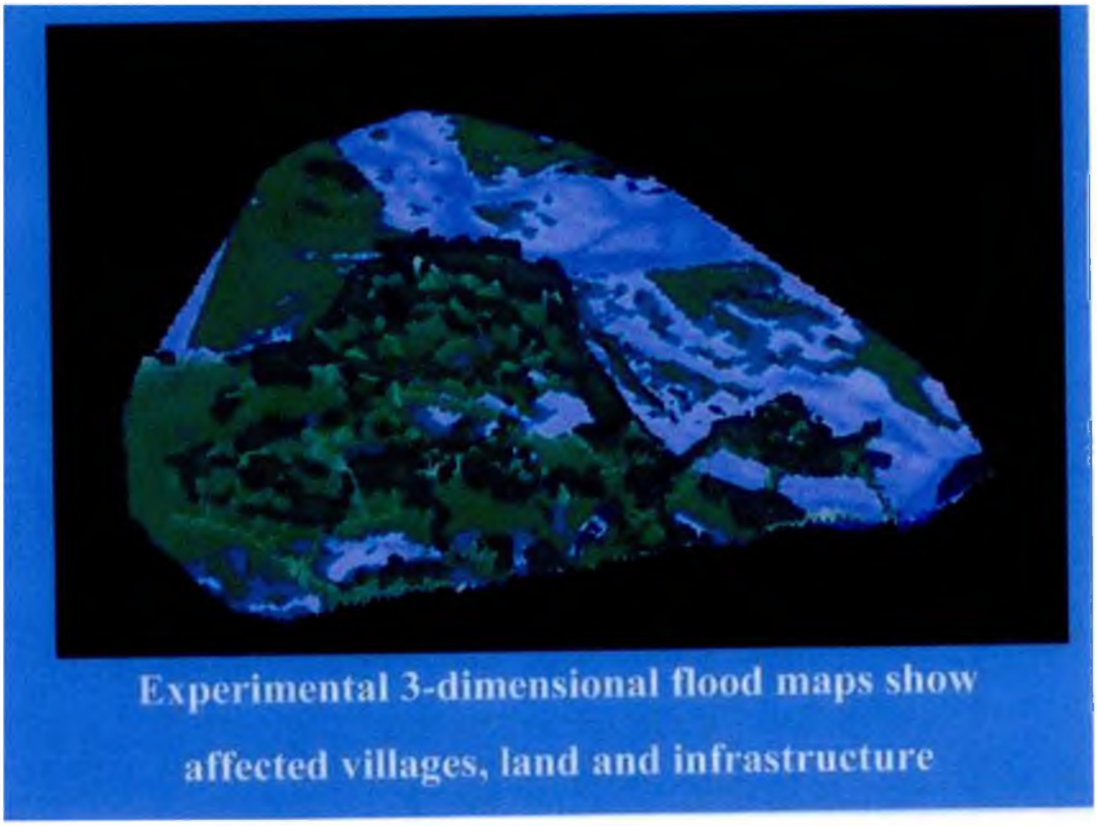


Figure 4.12: Digital Elevation Model of Tarapur Union
Source : Flood Forecasting and Warning Centre, (n.d.)

<u>*Tarapur Union*</u>

It is located in Gaibandha district. The FFWC has created accurate DEM for this area .From the DEM they can forecast the houses that will be under water during flood.

4.3.2 Flood Vulnerability in Munshiganj District

The area of the district is about 919 sq km and is bounded by the Jamuna in the west, the Padma and the Meghna in the south, the upper Meghna in the east and Lakhya in the north. The physiographic units of the area include the floodplains of the Padma, the Jamuna and Meghna and the Old Brahmaputra rivers. Ground elevation ranges from 1 8m above the sea level in the north to 4m in the south.

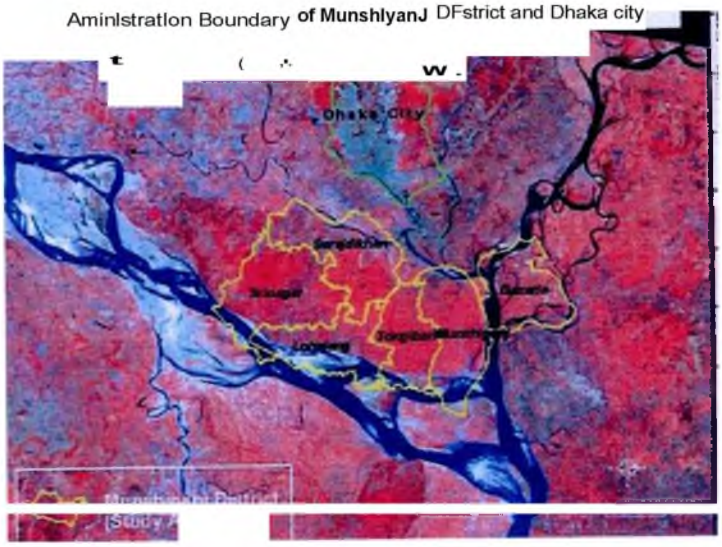


Figure 4.13: **Munshiganj District**
Source: Samarakun and Prathumchai, (n.d.)

Land use map

The vector data layers on land cover of the study area were generated for preparation of land use map. The data layers have been from aerial photographs taken during 1999-2000.

Flood area map

along with and RADARSAT were used for interpretation of the flooded and non-flooded This was generated combining optical and SAR data. ADEOS AVNIR, JERS SAR area.

During normal flood 61% of the study area is affected by flood and the affect is very prominent in the west.

Flood vulnerability map

Flood vulnerability map was generated by flooded area. Population information received from statistical department was in union basis.

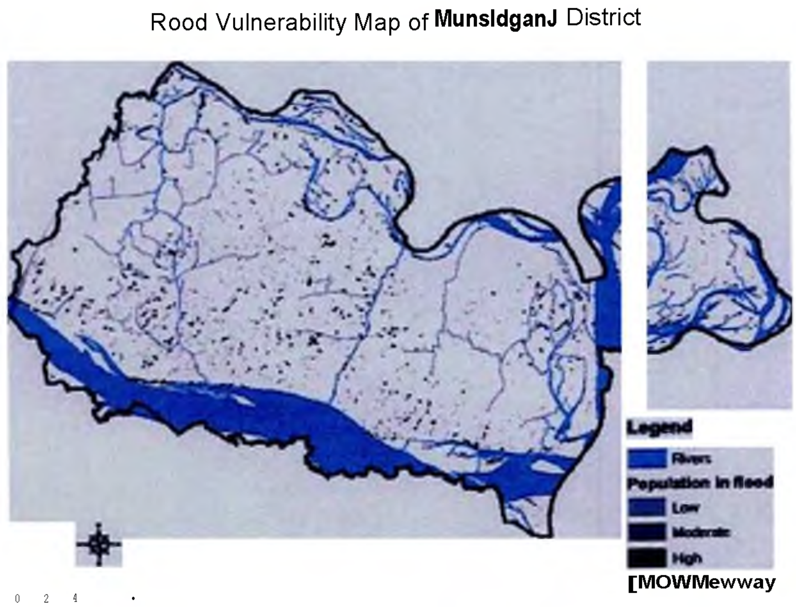


Figure 4.14: Flood Vulnerability Map
Source: Samarakun and Prathumchai, (n.d.)

It was found that almost all union of this district are inundated during flood season. Serajdikhan is the most affected upazilla due to its lower elevation. Lowest affected area is Tangibari.

It was possible to use satellite data for flood area mapping with reasonable accuracy using SAR and combining it with optical images. It may be required to combine with digital elevation model to rectify in areas where there is a high canopy cover.

From the above Bangladesh case studies it has been found that there are some specific thana or union wise projects done by non Government organisations which have detail GIS based flood mitigation plan. For these areas remote sensing has been used to create recent Digital Elevation Model. But if these plans are to be executed Bangladesh has to wait till 2016. Because Survey of Bangladesh is preparing the digital elevation model for whole Bangladesh which will take another 7 years.

CHAPTER 5

FLOOD MAPPING AND VULNERABILITY ANALYSIS

5.1 Mike 11

Mike I1 GIS has been utilised for the spatial presentation and analysis of one dimensional (ID) flood model results. Mike 11 GIS system integrates the mike I 1 river and floodplain modelling technologies with the spatial analysis capabilities of the ArcView GIS.

Mike 11 , developed by DHI water & environment, is a modelling package for the **simulation** of surface runoff, flow, sediment transport and water quality in rivers, floodplains, channels and **estuaries**. Once a model is established and calibrated, the ¡mpact of changes of artificial or natural origin on flood behaviour can be quantified and displayed as changes in flood levels and discharges. Mike • 11 is based on an efficient numerical solution of the complete non-linear St. Venant equations for I D flows. Mike 11 constructs a grid based water surfaces and compares these data with developed DEM to produce flood depth and duration mapped surfaces. MIKE 11 GIS produces three types of flood maps:

1. Flood inundation map or flood depth map
2. Flood depth duration map
3. Flood comparison map

5.2 Generation of flood map

Flood depth map have been generated on dates of normal and extreme flooding situation using hydrodynamic model simulations of FFWC model. These flood maps have been produced using the national DEM, which is based on 60's.

It is very likely that the areas which get inundated during a normal flooding scenario are expected to be inundated every year. Therefore, the regions have been taken as flood prone areas, which are inundated by more than 1 meter from a normal flooding condition during extreme flood events of 1998 and 2004. Chalan Beel in the northwest region and the haor areas in the northeast region of Bangladesh have not been taken into consideration as vulnerable **areas** since these low lying areas are deemed as water bodies during the monsoon season. Four areas have been identified as vulnerable areas.

Mike 11 GIS does not provide direct method to calculate duration of inundation within a given period. For this reason, duration of flooding within a time interval has been calculated from the generated daily flood depth maps. Flood depth more than 50 cm has been considered as flooding during the generation of these flood depth maps.

These flood maps can be used by various sectors for flood zoning, hazard mapping, damage and impact assessments on infrastructure, agriculture and fisheries. Specific objectives are as follows:

1) To generate water level at different locations for different hydrological conditions.
2) To produce flood depth map for specified return periods.
3) To produce depth duration map for specific return periods.

All maps are saved in grid format and the grids are then superimposed with union coverage prepared by WARPO from DLRS (Department of land records and Survey) mouza map. It has been found that bank line alignment of the three major rivers Padma, Meghna and Jamuna as demarcated in the National DEM has undergone lots of changes. So the bank lines of these rivers have been digitized using latest available satellite images.

5.3 Flooding scenarios in vulnerable areas

Vulnerable area I (VA1) is flooded by the Padma river, regional rivers and local rainfall. During monsoon season the predominantly high water levels in the major boundary rivers coupled with high water levels in the regional rivers e. g., Lakhya, Balu and rivers conveying spills from the Jamuna river prevent withdraw] of runoffs from excess rainfall in the internal floodplains. At the southeast corner the Meghna -Padma is influenced by tide, which causes further retardation of drainage in the area.

Vulnerable area 2 (VA 2) is floods by Arial Khan, Kumar and MBR river.

Vulnerable area 3 (VA 3) is flooded by regional rivers Bangali and Ichamati and further by the flows from the Jamuna river entering through the breaches. However, the area is not directly flooded for the Brahmaputra right embankment.

Vulnerable area 4 (VA 4) , which covers mainly Jamalpur and Tangail districts, is flooded by the old Brahmaputra river and spills from the Jamuna river through Jhanai and Pungli rivers.

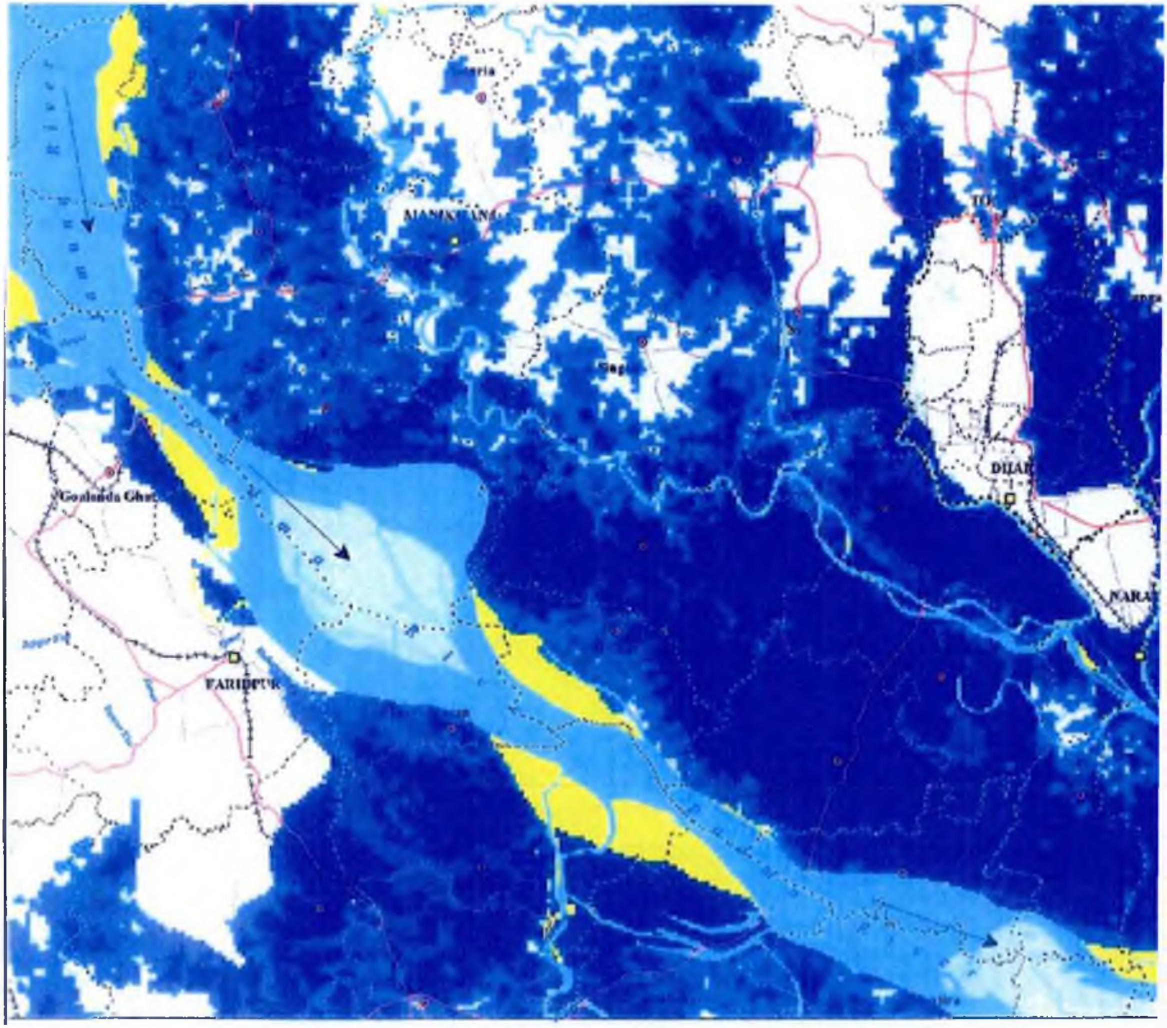
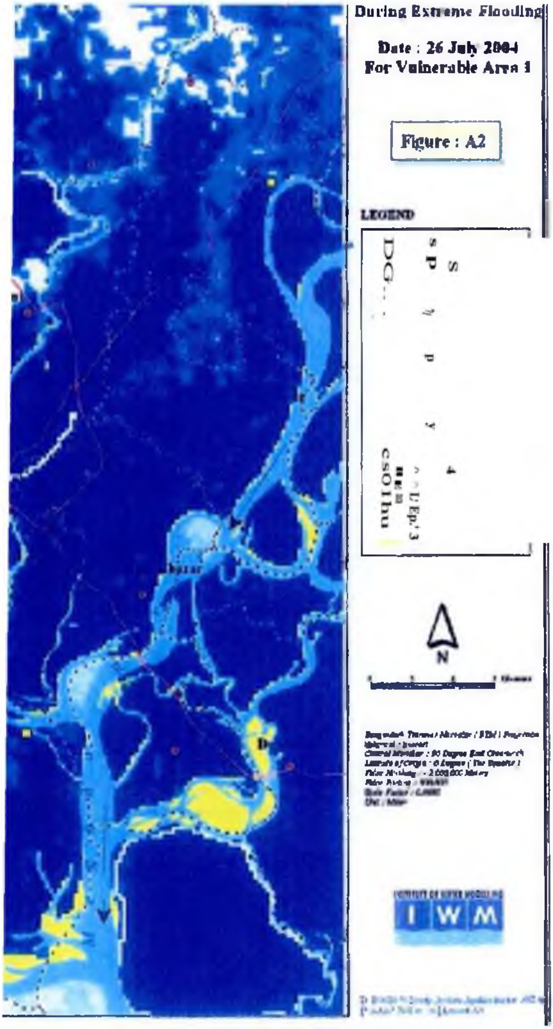


Figure 5.1: Flood Depth Map for Vulnerable area 1
Source: United Nations World Food Programme, 2007


During Extreme Flooding
Date : 26 July 2004
For Vulnerable Area 1
Figure : A2
LEGEND
N

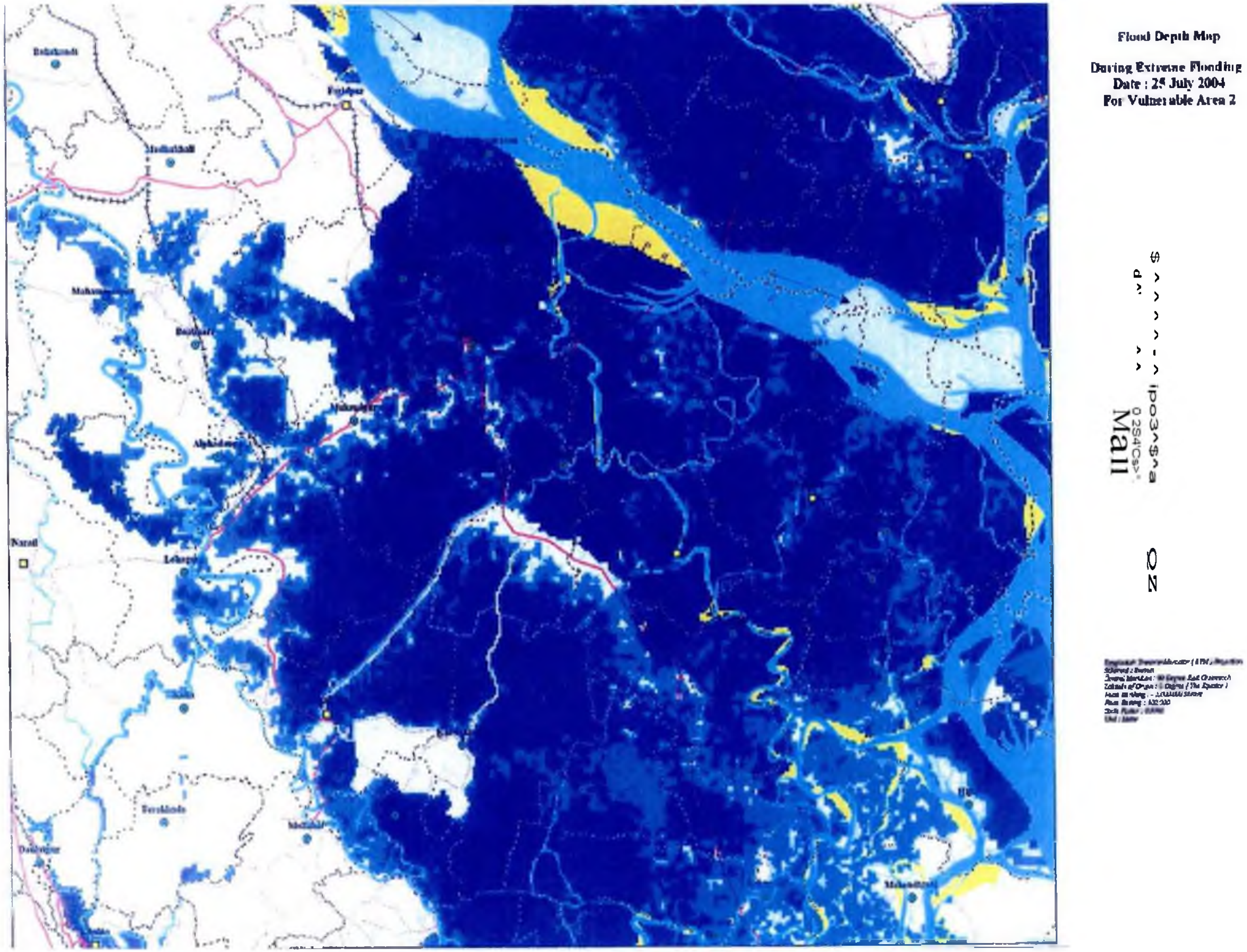


Figure 5.2: Flood Depth Map of Vulnerable Area 2
Source: United Nations World Food Programme, 2007

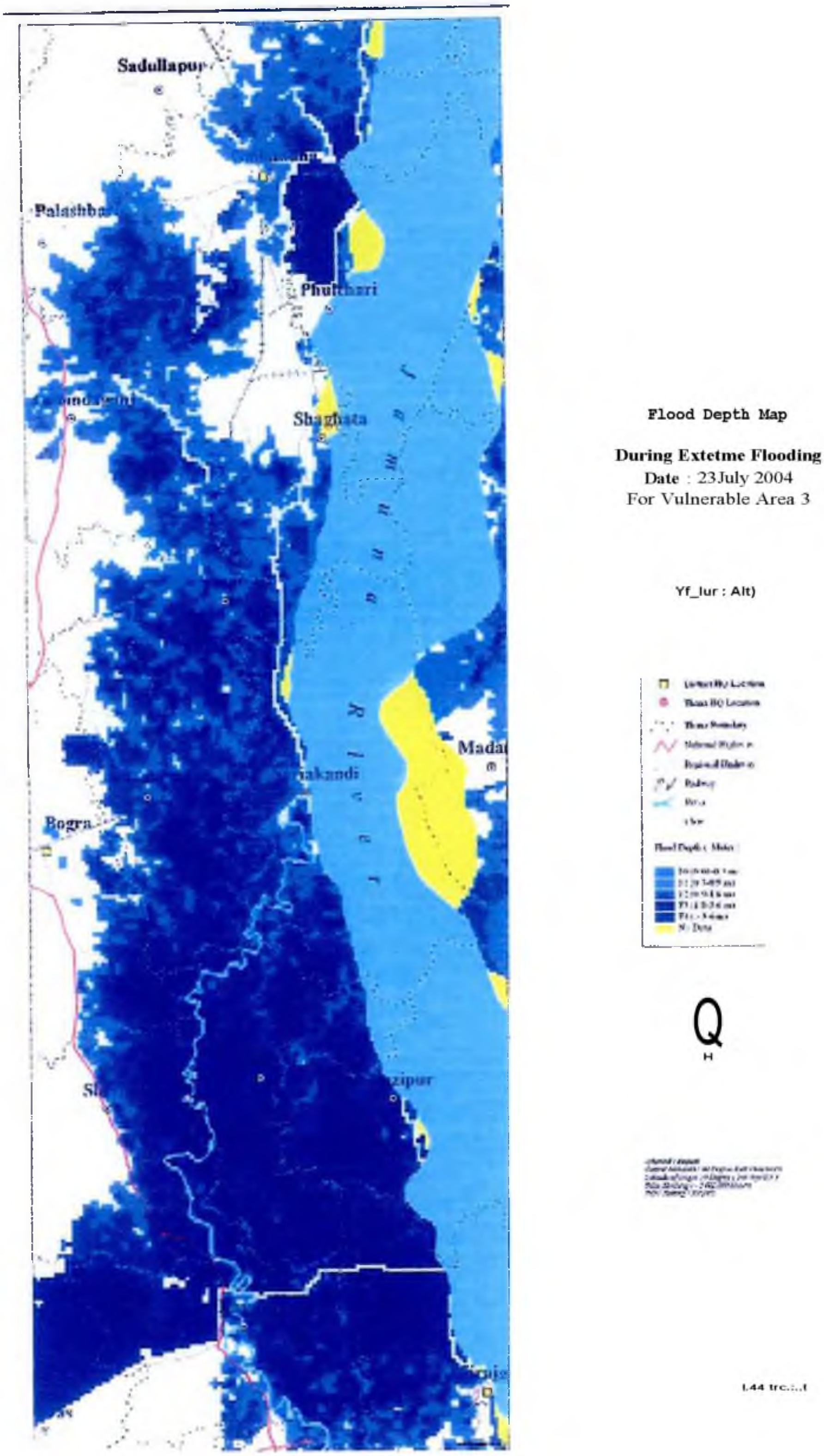


Figure 5.3: Flood Depth Map of Vulnerable Area 3
Source: United Nations World Food Programme, 2007

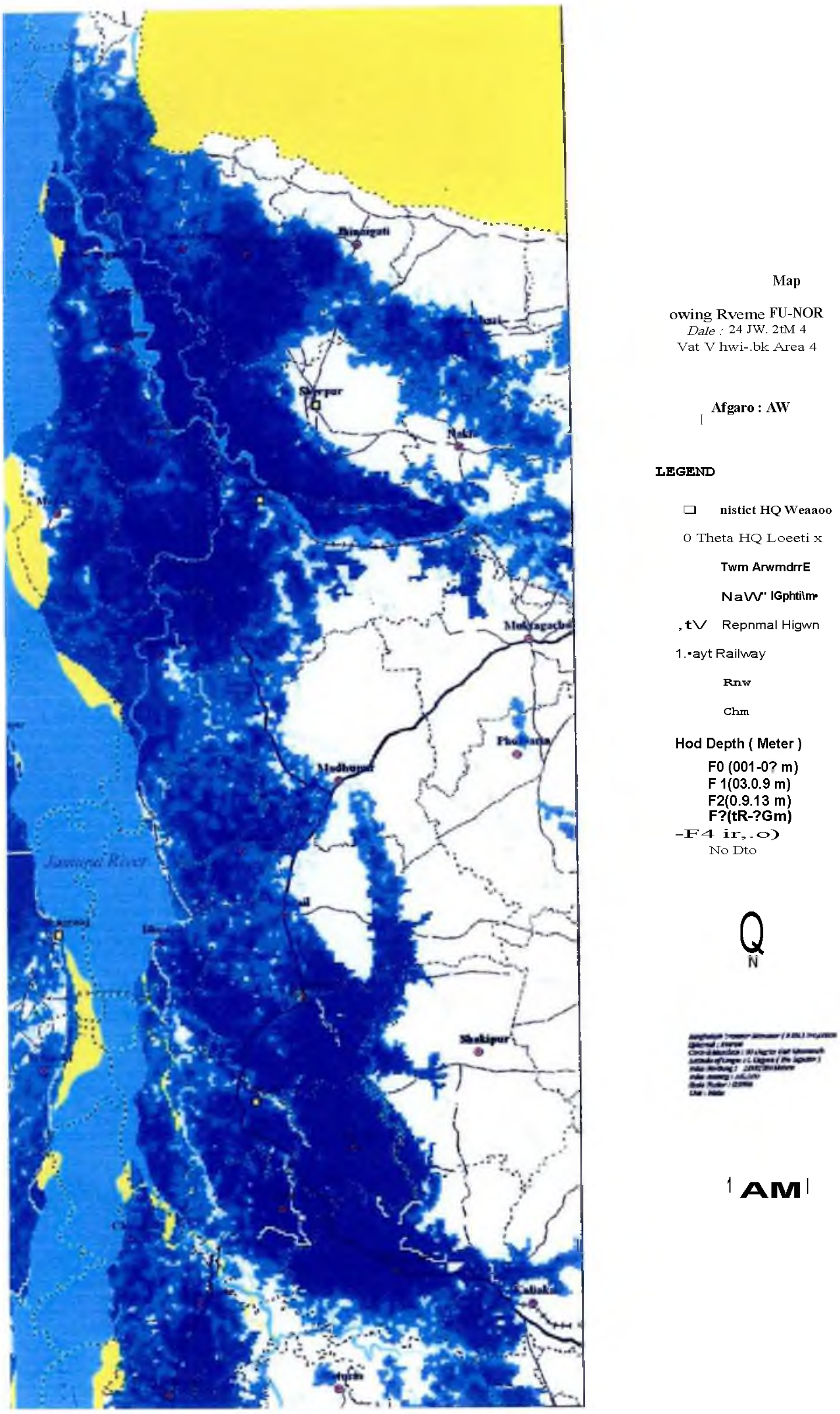


Figure 5.4: Flood Depth Map of Vulnerable Area 4
Source: United Nations World Food Programme, 2007.

5.4 Criteria for flood vulnerability

The accepted WARPO (Water Resources Planning Organization) Classification in terms of flood depth has been used for agricultural lands. The investigation has taken 5 days as the critical duration of flooding and thus the inundations for a period of 5 days or longer with flood depths higher than 50 cm threshold value have been taken into consideration in the calculation of flood vulnerability.

Table 5.1: Criteria for flood Vulnerability

Land classification	Depth of flooding
F0	0.01-0.30
F1	0.30-0.990
F2	
F3	1.80-3.60
F4	>3.60

Source: United Nations World Food Programme,

Ranking of unions based on flood vulnerability

Certain criteria have been devised to rank the unions under the 4 vulnerable areas depending on its vulnerability to flooding.

- **Vulnerability Index (Duration of Flooding)**

The vulnerability index developed on the basis of flood duration suggests the possibility of a union to **remain** inundated by a flood event similar to 2004. The scales used to calculate Vulnerability Index based on duration of flooding have been provided below in Table 5.2.

Table 5.2: Vulnerability Index (duration of Flooding)

Duration of flooding	Scale for vulnerability
0-5 days	0
6-20 days	1
21-35 days	2
36-50 days	3
51-60 days	4
66-80 days	5
81-90 days	6

Source: United Nations World Fool Programme, 2007

A sample calculation of vulnerability index for Suagram union (The most vulnerable union) is given below.

Vulnerability index(Duration of Flooding, From table 5.4)

_ (Col.6*0+col.7*1+col. 8*2+col.9*3+col.10*4+col.11*5+col.12*6)/]00

0.00*0+0.00*1+0.00*2+0.00*3+0.00*4+0.00*5+1.00*6)/100

=6.00

- **Vulnerability Index (Depth of Flooding)**

The vulnerability index has also been derived **based** on depth of flooding as obtained from depth duration maps. Vulnerability Index with reference to depth of flooding have been presented below in table 5.3.

Table 5.3: Vulnerability Index (Depth of flooding)

Depth of Flooding	Scales of vulnerability
Flood free	0
0.01-0.50 meter	0
0.51-1.50 meter	1
1.51-2.50 meter	2
2.51-3.50 meter	3
3.51-4.50 meter	4
4.51-5.50 meter	5
5.51-6.50 meter	6

*Source: United **Nations** World Food **Programme,***

- **Vulnerability index (Combined)**

The combined vulnerability index of each union has been calculated by taking the average value of two vulnerability indices.

Vulnerability index for Kaundia **union** (combined):

= (5.70+3.84))/2

= 4.77

Deliverable data and maps

The flood depth, depth duration and duration **maps** are provided in digital format (GIS grid format)

Conclusion

The flood maps produced from the digital elevation model of 1960. Considerable changes are there due to various developments. Also, flooding due to any accidental breach or overtopping of embankments is not reflected in the generated flood maps. Since the flood of 2004 is the most recent extreme event and therefore, hydrological setting of 2004 has been used for further **generation** of flood maps in the vulnerable areas. The maps should be reproduced when an updated better quality DEM is available.

Source: United Nations World Food Programme,

CHAPTER 6

FLOOD FORECASTING AND WARNING IN BANGLADESH

The present procedure for flood forecasting at FFWC is highly automated. Flood forecasting using the supermodel involves **a number** of key tasks which must be carried **out in a** specific order.

6.1 Flood Watch

Flood Watch is an Arc View GIS project. Three principle mapping activities are carried out within flood watch.

- Flood forecasting
- Real time stations display
- Thana status mapping

The supermodel has now the necessary data to perform a forecast simulation. The model is generally run from between 4 to 8 days before the time of forecast until three days into the forecast.

6.2 Flash flood forecasting

Flash floods differ from normal floods in the rapid rate at which the catchment runoff enters the rivers, and the rate at which the flood wave travels downstream. Normal flooding in Bangladesh develops gradually over a number of days or even weeks. Flash floods are much more dynamic and occur in a matter of hours following the rainstorm. The nature of the floods leaves little time for vulnerable people to protect themselves and their property.

The north-west flash flood model comprises the Karatoa-Atrai system, and the north east the Manu system.

1) North west flash flood model

Floods are forecast for Dinajpur and Bhushirbandar. Dinajpur is a boundary station for the supermodel and lies close to the international border. The river flowing through Dinajpur, the Punorbhaba, continues into India and reenters Bangladesh just north of Rohanpur on the Mohananda. There is no data available for the reach within India. Cross sections were derived for this reach from the hydraulic characteristics of the flow. Five real time water level stations were installed in the catchment. The model was extended downstream to ChapaiNawabganj which has a more reliable real time water level station.

2) North east flash flood model

The Manu catchment was selected for this study. There are four real time rainfall and water level stations. During development the Dhalai river proved to contribute as mucha s 30% of the flow in the Manu catchment. This is a scaled boundary. As Moulvi Bazar is an updating point, it is not of major importance to have a real time to have a real time boundary at Dhalai.

Flash flood forecasting was carried out with the northwest model only. Though the flash flood model is also set up for the north east, it was not possible to develop routine forecasting due to the irregularity of data transmission from Sherpur.

6.3 General Model

The general model (GM) developed under Mike 11 was adapted to real time operation in which boundary extended near to the Indian border on all main rivers. It comprises an area of around 102,000 km2 inside Bangladesh. The area within the greater Chittagong and Chittagong hilltracts districts is not included in the general model.

a) The rainfall runoff model (NAM

The rainfall runoff model (NAM) component of the general model comprises 41 land catchments and 7 river catchments. The area of eight catchments in the north east region have been extended beyond the national border.

The land area comprises the river basins of the mighty rivers: the Jamuna,the Ganges,The Padma and the Meghna; the basin of the major tributaries of the major rivers: Teesta, Atrai, Surma and Kushiara: the basin of major distributaries of the major rivers : Old Brahmaputra, Dhaleswari,Gorai and Arial Khan.

The direct way of validation of NAM model is to compare the generated runoff with observed discharge for different well-defined catchments In general model, four such catchments have been identified for comparison of simulated runoff against observed discharge. They have shown reasonably good agreement.

b) The hydrodynamic model (HD)

The model set up of the hydrodynamic model of general model usually consists of four parts; scematization of the rivers or channels, NAM catchments connection, cross section update and model boundaries.

In the general model there are 65 comparison stations.

- *The Brahmaputra Jamuna River*

There are eight water level comparison stations and one discharge station on the Jamuna river.They are Chilmari, Mathurapura,Kazipur, Sirajganj, Porabari, Mathura and Aricha.

- *The Ganges Padma River*

There are six locations: Hardinge Bridge, Talbaria, Sengram, Mohendrapur, Baruria and Mawa.

- *The Upper Meghna*

There are four water level comparison stations named: Ajabpur, Bhairab Bajar, Kalagachia and Meghna Ferry ghat.

Present FFWC model covers all major river system of Bangladesh. The **hydrodynamic result includes water level and discharge at un-gauged locations in** rivers and flood plains. Water levels from a MIke 11 simulation are stored in the water level grid points or h-points.

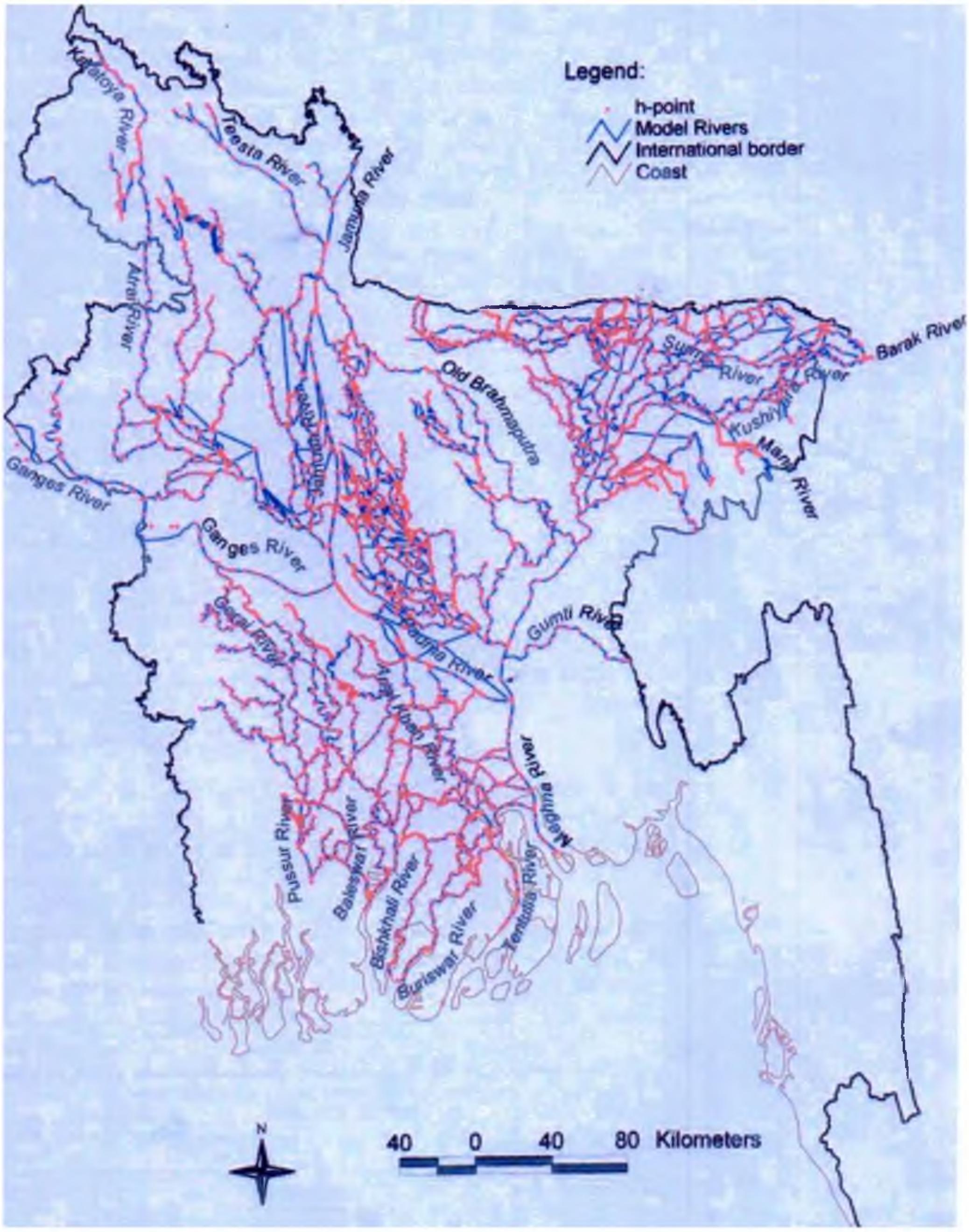


Figure 6.1: Water level grid points (h-points) FFWC model
Source: United Nations World Food Programme, 2007

Constraints Encountered during HD simulation

- **No measured data available at the boundary of Amalshid (S) and Amalshid (K) on the northeast region of general model.**
- **Some boundary like Rayenda, Patharghata water level data is not available for round the year. Generated data from Hiron Point was used as model boundary for those locations. Due to non-availibility of Daulatkhan station,** FFWC **data was used which misses the tide during day period.**

6.4 Model upgrading

A mathematical model of the Ganges -Brahmaputra-Meghna basin developed in MIKE BASIN platform is already available at IWM which will be completed by on month. MIKE BASIN is a water resource management tool developed by Danish Hydraulic Institute. The study will be conducted through updating of existing basin model.

River systems could be identified from physical maps of different states of India belongs to the basin available in the **Indian** web sites. Apparent topography of the **basin** area could be produced from SRTM DEM (90 m resolution) downloaded and processed at IWM GIS unit. Also a 1 km resolution DEM of USGS is available and will be used for verification.

There are also seven regional models

1) General model
2) South East regional model
3) South West regional model
4) North East regional model
5) North West regional model
6) North Central regional model
7) Eastern hilly regional model

1) General model

The general was first developed at IWM during Surface Water Simulation Modelling Programme Phase-I (MPO, 1988). During Phase iii of SWSMP, the GM was validated twice. In 1995 the model was validated for the years 1992-93 to 1993-94 (SWMC, 1996). It was further improved by redefining the spill descriptions along the left bank of the Jamuna to bring simulated spill volumes in line with those calculated by the more detailed North Central Region Model (NCRM).Using the **annual** hydrological and recent topographic data, the GM was updated in the last validation for five hydrological years:1998-1999, 1999-2000, 2000-2001, 2001-2002, and 2002-2003. The overall performance of the general model has remained constantly high over the years.

2) South East Region Model

The South East Region Model (SERM) covers the area lying to the south and east of Meghna river and Estuary, and north of Bay of Bengal. Much of the western boundary is formed by the international border with India, across which lie the Tripura Hills.

Most of the rivers originating in the hilly catchments in Tripura across the international border are flashy in nature, carrying high flood peaks in the wet season. The drainage network of the region includes the Gumti, Titas, Dakatia, little Feni and Noakhali khal plus many other khals.

3) South West Region Model

The south West Region Model (SWRM) covers the entire area lying to the south of the Ganges and west of the Meghna estuary. The Bay of Bay of Bengal and the international border with India from the Southern and Western boundaries respectively.

In the northern part of the model, the main nontidal river systemscomprise the Gorai, Arial Khan,Jayanti,and Upper Meghna and lower Meghna.The southern rivrs mainly comprise tidal estuary system, the largest being the Jamuna, Malancha, Passur-Sibsa, Baleswar, Tentulia and Lohalia.

4) East Region Model

This part lies to the east of the Old Brahmaputra and North of the Upper Meghna rivers .This region is bordered by the Shillong Hills and the Meghalaya Plateau, the Susang Hills in the north-west and the Tripura Hills in the South west. Rainfall in the Indian Hills is rapidly concentrated forming flash floods in the mountain **streams**, which sweep into Bangladesh. The central part is the Sylhet depression which is flooded during the Monsoon by backwater from the Meghna. The main source is the Barak river, which bifurcates to form Surma and Kushiara rivers. The tributaries are Sarigowain, Lubhachara, Manu, Khowai, Sonaibardal, Kalni and Dhaleswari.

In the west of the region, the Kangsha, Someswari and Mogra rivers drain a large part of the area. These rivers join the Dhanu and Baulai rivers, which in turn capture additional flash flood.

5) North West Region Model

This region is bounded by the Brahmaputra River to the east, the Ganges to the South and the international border to the north and west. An extensive area of depressions or beels exists in the south central part of the region. This area is called Chalan Beel. It is a huge flood retention reservoir. The main source of inflow is local rainfall and spilling from Jamuna and '1'eesta.

The Karatoa-Atrai-Baral and the Jamuneswari-Karatoa-Bangali are the two main systems draining the greater part of the north west region. Other river systems are Dudhkumar , Dharla, Tangon-Punarbhaba-Mohananda.

6) The North Central Region Model

The North Central Region Model covers the region bounded by the Jamuna, Ganges, Meghna and Old Brahmaputra, and includes Dhaka.

The central part of it features low forested hills known as Garhs.Consequently, high river stages in the two rivers impede the drainage of the region.The main spill fed rivers are Old Brahmaputra, Jhenai, Dhaleswari Kaliganga, Bangshi, Turag and Buriganga.The rain fed rivers are Khiro, Banar, Lakhya.

7) Eastern Hilly Region Model

This model consists of five river basins, which are not connected. These are Karnafully-Halda, Sangu, Matamuhuri, Muhuri-Feni, and Bank Khali. They separately drain in the Bay of Bengal.

Supe oriel

The development of the Mike 1I model for flood forecasting in Bangladesh has been a continuous process from the incipient stages of FAP 10 to the present final product. The model is a combination of the general and three northern region models developed in SWMC. It is referred to as the supermodel. Supermodel now is in operational at FFWC covering entire northern flood affected area of Bangladesh. The areas are subdivided into 107 sub-catchments. It includes 195 river branches, 207 link channels, 40 Broad crested Weirs.

The supermodel is an integrated updated model of general model and the northern regional models.

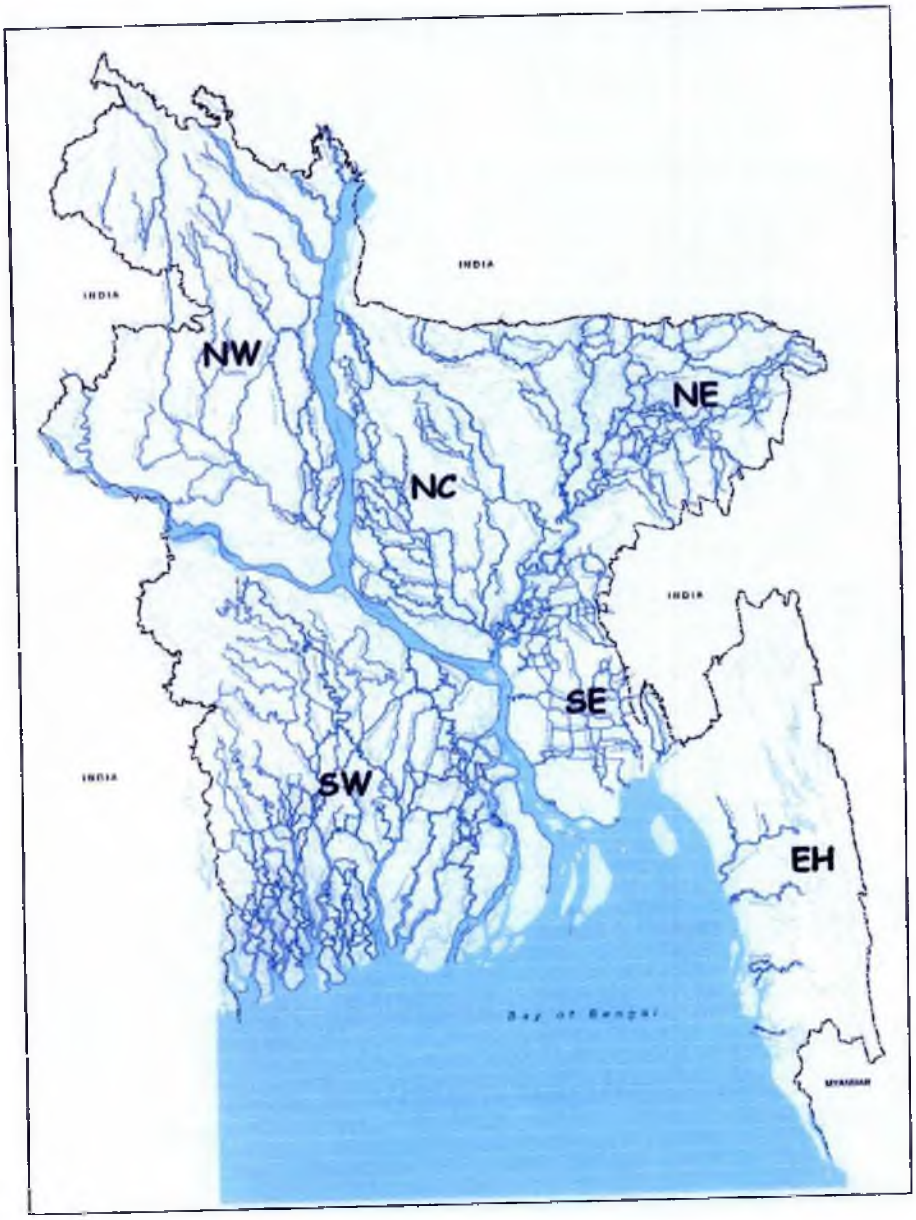


Figure 6.2: Six Regional Models
Source: Bangladesh Water Development Board, 2007

6.5 Model **performance, 2008**

38 stations which are located in the model area are taken for evaluation.

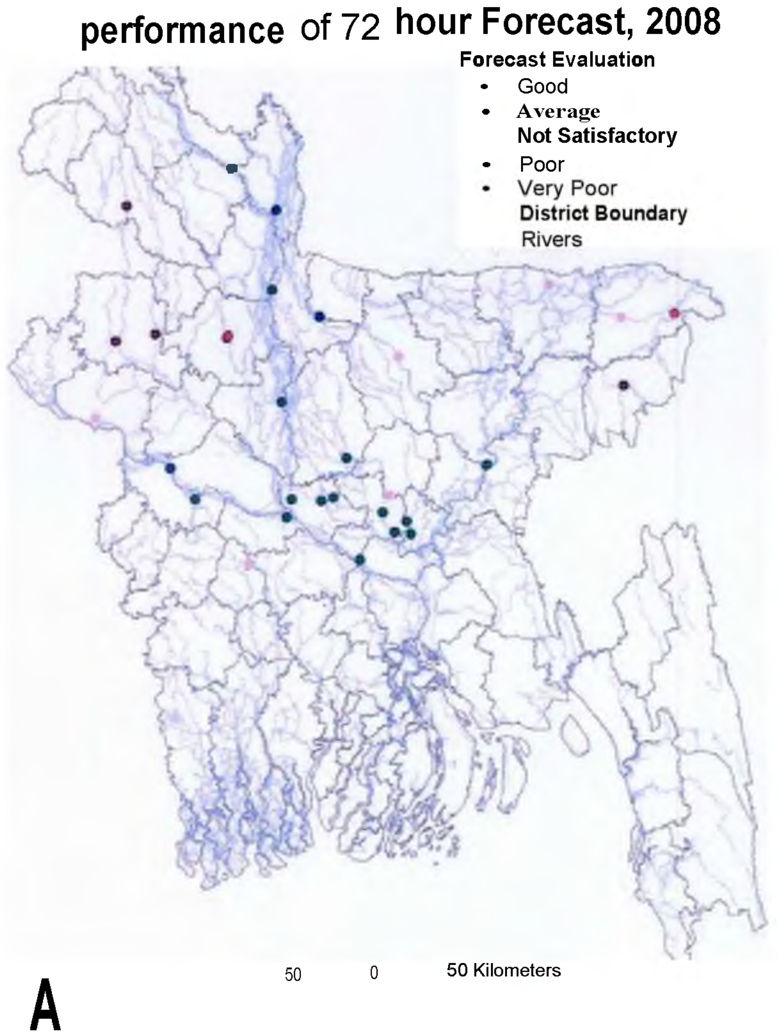


Figure 4.3: 72 **hr Forecast Evaluation** (**Year, 2008)**

Figure 6.3: 72 Hr **Forecast Evaluation (year, 2008)**
Source: Flood Forecasting and Warning Centre, 2008

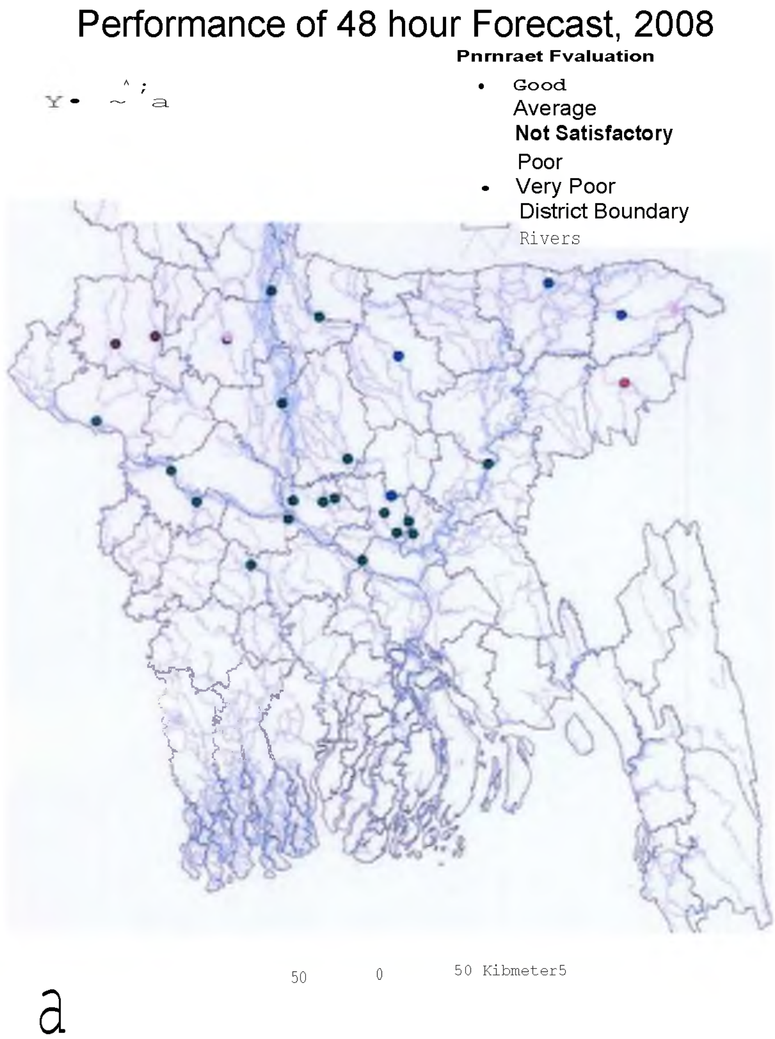


Figure 4.2: 48 hr Forecast **Evaluation** (Year, 2008)

Figure 6.4: 48 Hr Forecast Evaluation (Year, 2008)
Source: Flood Forecasting and Warning Centre, 2008

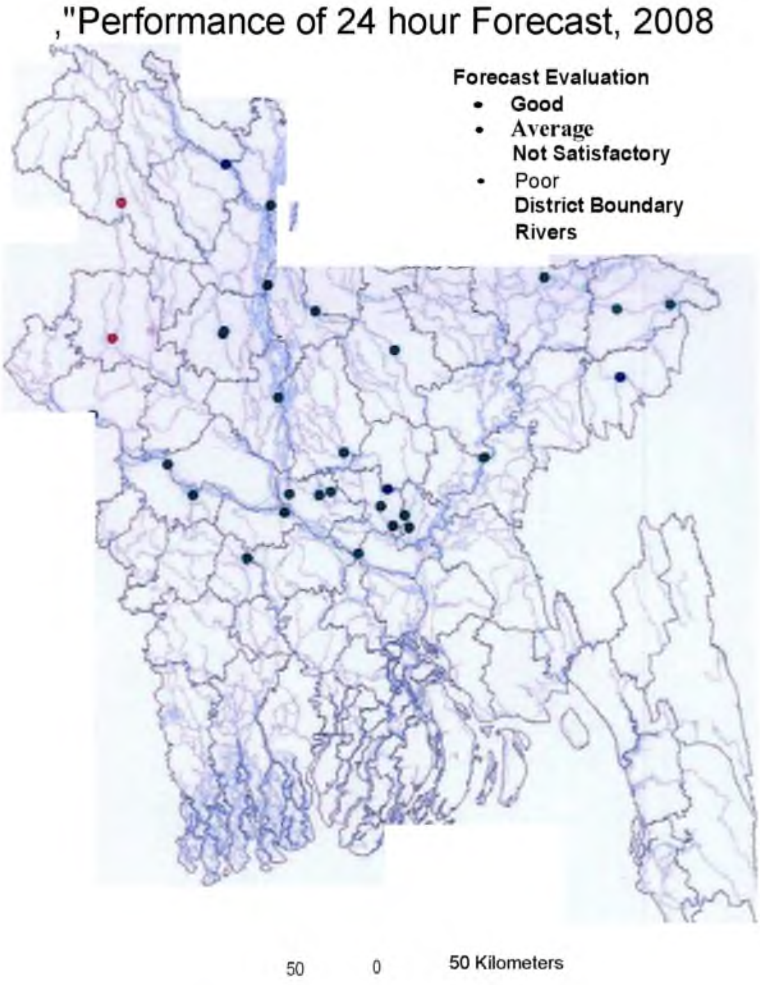


Figure 4.1:24 **hr Forecast Evaluation (Year, 2008)**

Figure 6.5: 24 Hr Forecast Evaluation (Year, 2008)
Source: Flood Forecasting and Warning Centre, 2008

6.6 Use of Remote sensing technology

Hydrodynamic mathematical models are the only tools used extensively, and the utility of these models varies with their scale, complexity of the flood environment and availability of information for model verification and calibration. Aerial remote sensing is expensive and highly restricted by the Government, and thus has limited applications, Satellite remote sensing technology can provide some of the required monitoring information at frequent intervals with timely and cost effective delivery. Radar images are nearly not affected by cloud coverage during the monsoon and thus have high potential for application in flood monitoring. Since 1998,EGIS has continued with a number of additional applications oriented development projects using satellite SAR as the basis for monitoring flood extent during the monsoon . One such project was the operation of a portable SAR ground station, implemented jointly with SPARSO.

For a more detailed analysis, EGIS also conducted a research and development project in cooperation with the CPP interventions in Tangail. In this project a multi temporal set of nine RADARSAR images was acquired for the same area for the period May through December, 1998.These images were used to develop a successful method for crop monitoring, flood damage assessment at a local level and integration with HD model.(EGIS ,2000).A large number of organizations used EGIS flood 1998 information for assessing damage and thus perform relief operations.

EGIS in collaboration with SPARSO, has installed a ground receiving station for European Remote Sensing Satellite -1 and 2 (ERS 1& 2) sensors in April 1999, which is now fully operational.

6.7 Discussion

Flood maps have been produced from the Hydrodynamic models which have been produced using the National DEM, based on survey data of 60's.

Land levels in and around the city areas might have undergone remarkable changes to city development, housing development, road network development etc. Hence the flood depth estimation for those areas might be higher than the actual situation.

Due to different shortcomings including upstream hydrological information, detail and accurate digital elevation model and limited technological development of the Flood Forecasting centre, the services were not fully satisfactory to all corners. Area inundation forecast have been indicative, based on a coarse digital elevation model

and old topographic maps. Information flash flood was limited due to non-availability of real time data at a much shorter interval than the usual.

During the flood season of 2008, close interaction between policy makers, International agencies helped in taking appropriate action to mitigate flood hazards. The people of the country were also well informed about the flood situation. The Flood forecasting and Warning Centre took the privileged to reflect the flood situation as accurate as reliable as possible.

The flood of 2008 was fairly normal compare to devastating flood of 1987, 88, 98 and 2007. The accuracy of flood forecasts issued by FFWC for major river flood forecasting is around 96%, 90%, 85% for forecast of 24, 48, and 72 hours.

CHAPTER 7
CONCLUSION AND RECOMMENDATIONS

Bangladesh is applying the GIS technology in an advanced form but technical issues take time to be effective for it need expensive tools and packages Comparing with the international GIS applications in flood management field Bangladesh is in a remarkable position The model performances are very good and some case studies shows that if the accurate digital elevation model can be prepared it is possible to handle and mitigate flood in grass root level. The space technology is also complementing GIS to the flood management programme.

Considering the limitations the following points have been suggested to develop the Future Flood Management of Bangladesh by GIS.

1) Presently, the accuracy of the flood inundation maps low due to outdated topographic information. The source of currant current digital elevation model is 1:50,000 topographic mapping in the 1960's.

The survey of Bangladesh has initiated a project for updating digital maps with financial assistance from JICA. The duration of the project is up to 2012. But they will require time up to 2016.They should prepare them on priority basis.

2) Bangladesh is the lowest riparian of three major river basins and 93% of basins runoff comes from the upstream countries that are China, Nepal, Bhutan and India. During monsoon season limited amount of data is transmitted from India. These have constraints with respect to lead times. The lead times are 48 hours for central part and 4 hours for **areas** near the border. Higher lead times are required for flood forecasting.

Appropriate action Plan is needed for smooth data transfer among the countries.

3) Uncertainties in the future changes in climate acts as a barrier for preparing long term flood forecasts, but reliable forecasts of climate changes are required to improve ate accuracy and extend the lead time of flood forecasts.

Development of tools for the incorporation of the CFAB Product into the Bangladesh flood forecast mode.

4) It is not possible for FFWC to forecast flash floods in the NE region of Bangladesh. Because of inaccessibility to rainfall data over the boundary and also no real time continuous rainfall measurement station in Bangladesh.

Rainfall maps for the catchment for 3 and 6 hour forecast period are needed. Generation of inundation maps for 6, 12, 24 and 72 hour forecast periods have to be ensured.

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